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Effectiveness of using a magnetic spectrograph with the Trojan Horse method

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Abstract. The Trojan Horse method relies on performing reactions in a specific kinematic phase space that maximizes contributions of a quasi-free reaction mechanism. The hallmark of this method is that the incident particle can be accelerated to high enough energies to overcome the Coulomb barrier of the target, but once inside the target nucleus the relative motion of the clustered nuclei allows the reaction of interest to proceed at energies below this Coulomb Barrier. This method allows the experimentalist to probe reactions that have significance in astrophysics at low reaction energies that would otherwise be impossible due to the vanishing cross section. Traditionally the Trojan Horse method has been applied with the use of silicon detectors to observe the reaction products. In this study we apply the Trojan Horse method to a well studied reaction to examine the potential benefits of using a splitpole magnetic spectrograph to detect one of the reaction products. We have measure the three body ^{7}Li(d,αn)α reaction to constrain the energy ^{7}Li(p,α)α cross section. Measurements were first made using two silicon detectors, and then by replacing one detector with the magnetic spectrograph. The experimental design, limitations, and early results are discussed.

1. Introduction

The Trojan Horse method (THM) is an indirect approach to estimating reaction cross sections at energies below the Coulomb Barrier. This technique has been the topic of many publications covering the method's theoretical and experimental attributes, e.g. Refs. [1-5]. Here we apply the THM to a well studied reaction that can be used to estimate the low energy cross section of the astrophysically important ^{7}Li(p,α)α reaction [1]. We are interested in the quasi-free (QF) ^{7}Li(d,αn)α reaction that will be used to determine a relative cross section the 2-body ^{7}Li(p,α)α reaction. The THM usually uses of silicon detectors to measure reaction ejectiles in coincidence. Our aim is to evaluate potential benefits of measuring the emerging nuclei with a combination of a magnetic spectrograph and one silicon detector, rather than exclusively using silicon detectors.

2. Experimental Setup

In this study, performed at the IPN-Orsay Tandem Accelerator, we bombarded a 200 μg/cm^2 CD_2 target with a 20 MeV ^{7}Li beam with currents between 10 and 150 enA. We measured outgoing α-nuclei under strict kinematic conditions that make the QF reaction mechanism favourable [1]. Initially we used two silicon detectors and then later replaced one with the Splitpole magnetic spectrograph. The two silicon detectors were placed at $(45.3 \pm 0.7)^\circ$ and $(44 \pm 1)^\circ$. The latter was replaced by the magnetic spectrograph which was placed at $(45.55 \pm 0.5)^\circ$; note that all angles are relative to the beam axis. A set of collimators were applied to the silicon detectors during both arrangements that were used to constrain the acceptance angle of each. Energy calibration of the silicon detectors was performed using a triple-α source and two additional α energy lines retrieved by the position sensitive detector within the spectrograph after gating on α-nuclei. This latter approach served to provide the energy calibration of the spectrograph itself.

3. Kinematic Data Selection

QF yield is maximized by constraining the relative angle (θ_{12}) of the emerging alpha particles, α_1 and α_2, to be 90°. This angular separation was used to determine the detector placements during both phases of the measurement. Constraining θ_{12} also helps ensure that the energy given to the spectator (neutron) in the reaction will be minimized. Despite the careful selection of the QF reaction mechanism the sequential decay (SD) of ^{8}Be* is expected to have a strong contribution in this kinematic phase space. Kinematic calculations revealed that low spectator energy corresponds to α-α coincidences in an arc with α energies between 14 and 21 MeV. Our measurement agrees with kinematic calculations which can be seen in Figures 1 and 2. The data that were selected for further analysis, i.e. those corresponding to the QF mechanism, are shown in red.

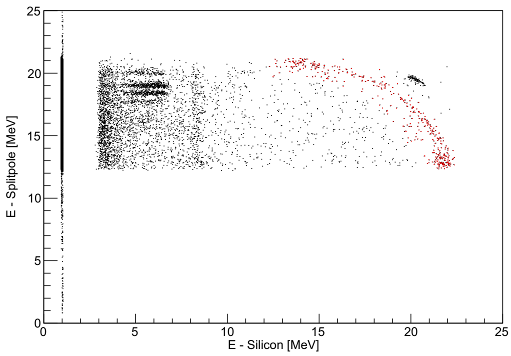

Figure 1. Two dimensional energy spectrum of α_1-α_2 coincidences in the silicon-spectrograph setup.

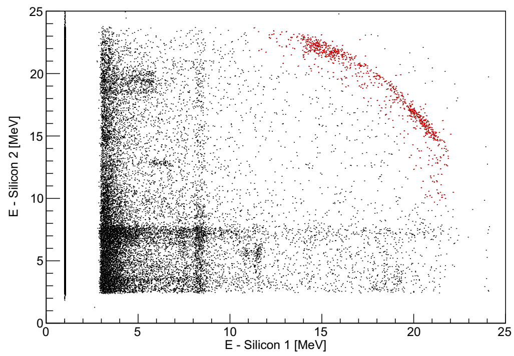

Figure 2. Two dimensional energy spectrum of α_1-α_2 coincidences in the silicon-silicon setup.

According to the results of Ref. [1], the QF mechanism is expected to dominate the reaction yield for spectator momenta less that 40 MeV/c, whereas SD events become preferred when that limit is exceeded. Figures 3 and 4 show the spectator momenta for the two setups. The relative energy in the QF entrance channel by: $E_{7Lip} = E_{\alpha1\alpha2}$ - Q_2 [7] where $E_{\alpha1\alpha2}$ is the relative energy of the emerging α nuclei and Q_2 is the Q-value of the two-body reaction of interest. In this arrangement δE_{7Lip} has a strong dependence on the uncertainty in the relative angle of the emerging α nuclei. In the silicon-silicon and silicon-spectrograph setups the relative angles were $\theta_{12} = (89 \pm 1)^\circ$ and $(90.9 \pm 0.9)^\circ$, respectively. The angular positions of the detectors were limited by uncertainties related to collimator size, direction of the beam, and readability of the ruled angular positions of the silicon detectors within the reaction chamber.

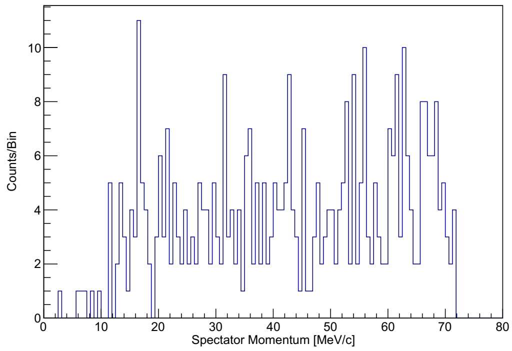

Figure 3. Spectator momentum spectrum from silicon-spectrograph setup.

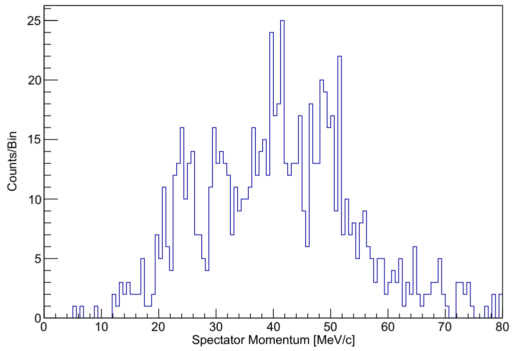

Figure 4. Spectator momentum spectrum from silicon-silicon setup.

4. Conclusion and Outlook

The aim of this work is to evaluate the possible advantage of using a magnetic spectrograph in Trojan Horse studies with respect to traditional silicon detectors. The well-known ^{7}Li(p,α)α reaction studied by the THM in the past [1] has been used as a benchmark for our work. In this work we have used a the Splitpole magnetic spectrograph at the IPN-Orsay Tandem Accelerator facility in Orsay, France. Our analysis is in progress but our early findings are shared here.

Our data show strong kinematic similarities with the data presented in Ref. [1], with the loci shown in our 2-D coincidence spectra and the range of associated spectator momenta both in reasonable agreement with expectations. Work is underway to select QF yields more carefully based on calculated SD contributions. This will allow a more rigorous comparison to the data of [1]. We have found that δE_{cm} has strong dependence on θ_{12}. Although the Splitpole is expected to reduce uncertainty in the energy measurements of emerging nuclei, further measures are needed to constrain $\theta_1 + \theta_2$ to determine the relative angle between the detectors to higher precision. Looking forward, cross section estimates of the ^{7}Li(p,α)α reaction will be determined and normalized to directly measured results [8, 9]. Afterwards, a comparison will be made to the results of reference [1] to gauge any possible advantage to incorporating a magnetic spectrograph in Trojan Horse experiments.

Acknowledgments

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